Problem 6
ITPO 2021

1 Sample Detector Ideas

This problem was designed to be open-ended and inspire some phenomenological discussion. Since we currently have many potential models for dark matter, it was especially important to identify what candidates you are targeting with your detector. Possible detector optimizations and the parameter space of observable candidates will vary with detector design of course, but this can be usually estimated from reference papers so we will not dive into that here. Also, when designing a detector of any kind, it is important to account for things like noise or sensitivity. This was the reason for the lack of financial or practical constraints—you could place your detector wherever you wanted with various physical properties to account for these considerations.

Below, we provide brief, qualitative descriptions of example detector ideas. These are simply interesting concepts meant to further inspire some thought—they are not ranked in any particular order and their relative practicality (or lack thereof) is not addressed. Recall that the proposed detector had to be constructed from paper, glue, and scissors. Given the purposefully open-ended nature of this problem, specialized versions of these materials were allowed such as papers made from nitrocellulose or carbon fiber.

1.1 Fossil

One interesting proposal for DM detection is called paleo-detection, and involves searching for fossilized tracks of WIMPs in excavated rocks and minerals as opposed to alternative live detection methods which aim to identify events in real time [1][2][3].

The idea is that as a WIMP passes through some material (ideally with a regular crystal lattice structure), it might scatter and interact with a nucleus in the lattice to provide a kinetic kick of a few keV. This nucleus is estimated to travel a distance of order 10 nm through the crystal. Along the way, as it scatters off of electrons and other nuclei, it would leave a “damage track” in the regular crystal lattice. This path of damage would remain fossilized in the material, and can be identified by its length and broken pattern relative to the rest of the crystal lattice. To start looking at more useful references, check out the Letter of Interest on Paleo Detectors from this year’s Snowmass2021 [4].

Recent papers [5][6][7][8][9] involve using various microscopy technologies to methodically search for these damage tracks in excavated natural minerals. Helium Ion Beam Microscopy (HIBM) and Electron Microscopy (EM) would provide greater resolution when scanning than X-ray Microscopy or Scattering techniques, but also require that the sample is broken up into pieces which would then be scanned for traces of persistent damage. Since we are not limited by practical constraints in this problem, we can propose the use of multiple layered sheets of material, which are then separated after years of “data collection” to be slowly and methodically scanned through HIBM or EM.

To further hedge our bets, we can assemble this layered detector in space and make it far larger than Earth to maximize our dataset. Regarding the material used, the papers references above point to certain crystalline minerals in rocks and underground deposits as ideal candidates (for some obvious reasons). In order to replicate this with our own materials (paper and glue), we have to get creative. One method would be to first find a large exoplanet with massive pools of dissolved salts or minerals. Then, by placing large sheets of paper in these pools we can provide a perfectly flat surface onto which the dissolved minerals will solidify to form crystals. After “growing” our crystal sheets, we can then arrange them in space and carry out our experiment.

1.2 Flame

Current dark matter detection strategies assume that dark matter consists of non-interacting particles with a reasonably large number density. These detection strategies become entirely unfit if there are significant self-interactions within the dark sector. Self-interacting dark matter particles could potentially coalesce into much larger composites, which act as more massive objects than the individual particles but have a much lower number density.

If we want to build a detector of these dark matter composites, we can leverage their higher mass but must account for the lower density of events. These “blobs” of dark matter could exist at various scales depending on coupling strength, so we could rule out regions of parameter space for self-interacting dark matter by setting constraints on blob size—please refer to the papers and related works for more information [10][11].

While WIMPs from our previous example were estimated to deposit a few keV, clusters of self-interacting dark matter could reasonably deposit on the order of 10 MeV. This is a much more energetic interaction so instead of following conventional detection methods, let’s make use of the unrealistic nature of this problem.

When paper is treated with a mixture of sulfuric and nitric acids, it can be turned into nitrocellulose. Normally nitrocellulose is a mix of trinitrates and dinitrates, but in principle could be completely converted to cellulose trinitrate. This gives us a few advantages: highly nitrated cellulose is incredibly unstable at high temperatures and will readily combust even at temperatures around 125 Celsius [12]. This material is used in gunpowders, solid rocket propellants, and explosives. The surface of nitrocellulose is also more homogeneous, smoother, and has fewer and narrower pores. In fact, there is a precedent for the use of nitrocellulose in paper based sensors and nuclear track detectors (for which there are many papers online) [13][14].

We can take advantage of the unstable nature of nitrocellulose, and the larger estimated deposited energy from our clusters of self-interacting dark matter, to build a sensitive detector for our candidates. And by placing the detector in space and making it incredibly large, we can solve the issue of our dark matter clusters having a lower number density than conventional non-self-interacting dark matter particles. Furthermore, if we build this large, sensitive structure inside of a warm, oxygen-rich cloud, we could conceivably heat our detector to just below its combustion point. Once shielded by thick walls of paper and glue to prevent unwanted interactions, we could homogeneously modulate the temperature of our paper detector to tune the “trigger” sensitivity to match the kinetic kick from our dark matter cluster, which would vary based on coupling strength and cluster size. Using this method, one could look out for spots of spontaneous combustion which would mark any meaningful dark matter interactions.

1.3 Light

Instead of altering our paper, we could try using our glue to build a detector. In fact, this lets us recreate current direct detection methods in a straightforward manner. We can use our glue in at least two ways: firstly, attempt to produce a plastic scintillator based on epoxy resins [15][16][17]; secondly, we can use our specialized “glue” as a radiation-hard optical cement to hold our detector together [18].

It may be difficult to find naturally occurring thallium-doped sodium iodide crystals, but NaI scintillating crystals may exist on some exoplanet as well as liquid xenon. With these components one can imagine recreating detectors such as DAMPE [19], COSINE-100 [20], ANAIS-112 [21], LUX/LZ [22], XENON1T [23], etc.

1.4 Pendula

It is possible to probe dark matter using measurements of gravitational waves, and one could make a torsion-bar antenna out of paper and glue to possibly make such measurements [24].

We could also operate at a smaller scale and use “a billion millimeter-sized pendulums.” If we isolate fibers from our paper to make very small pendula, we can arrange them in a dense grid behind a wall of insulating material. WIMPs which pass through our grid of pendula will then create a track as they disturb the motion of our pendula through gravitational interaction [25].

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